DC-GHz Micromachined Capacitive Air Transducers

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Outline

- Introduction and Approach
- Traditional detection and performance of resonant capacitor transducers
- Broad band detection and potential improvement in sensitivity
- Conclusions

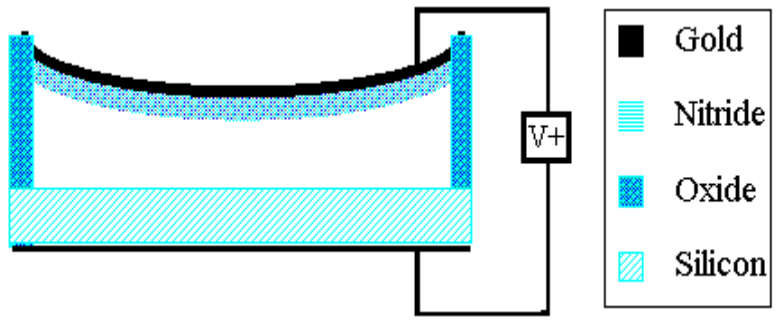
Capacitor Micro-machined Ultrasonic Transducer (cMUT)

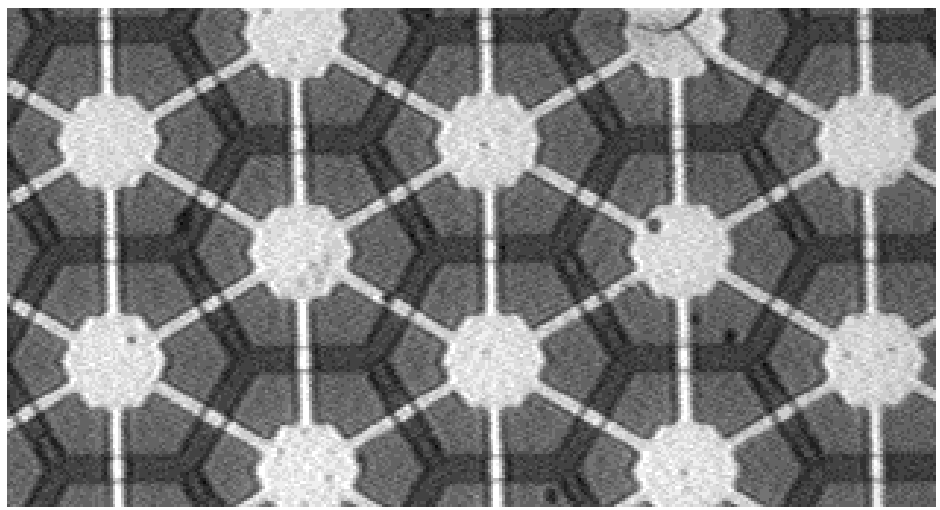
- **Thin (~1 μm), 50 μm radius, metalized nitride membranes suspended above silicon substrate.**

- **Several thousand electrically connected in parallel form the transducer.**

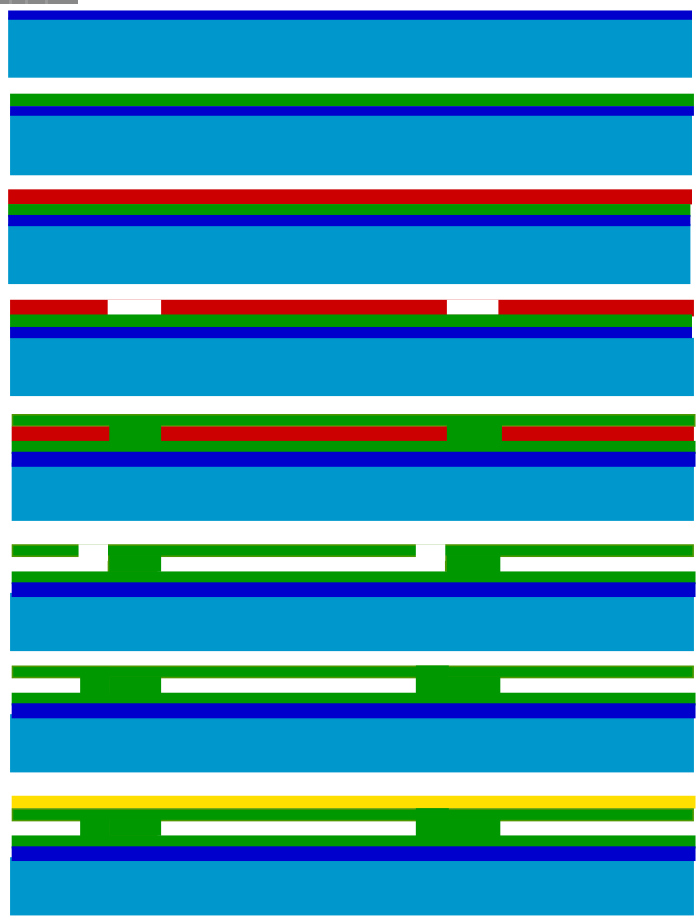
- **Resonant structure has dynamic range in excess of 100 dB.**

- **Electric field 10^9 V/m**



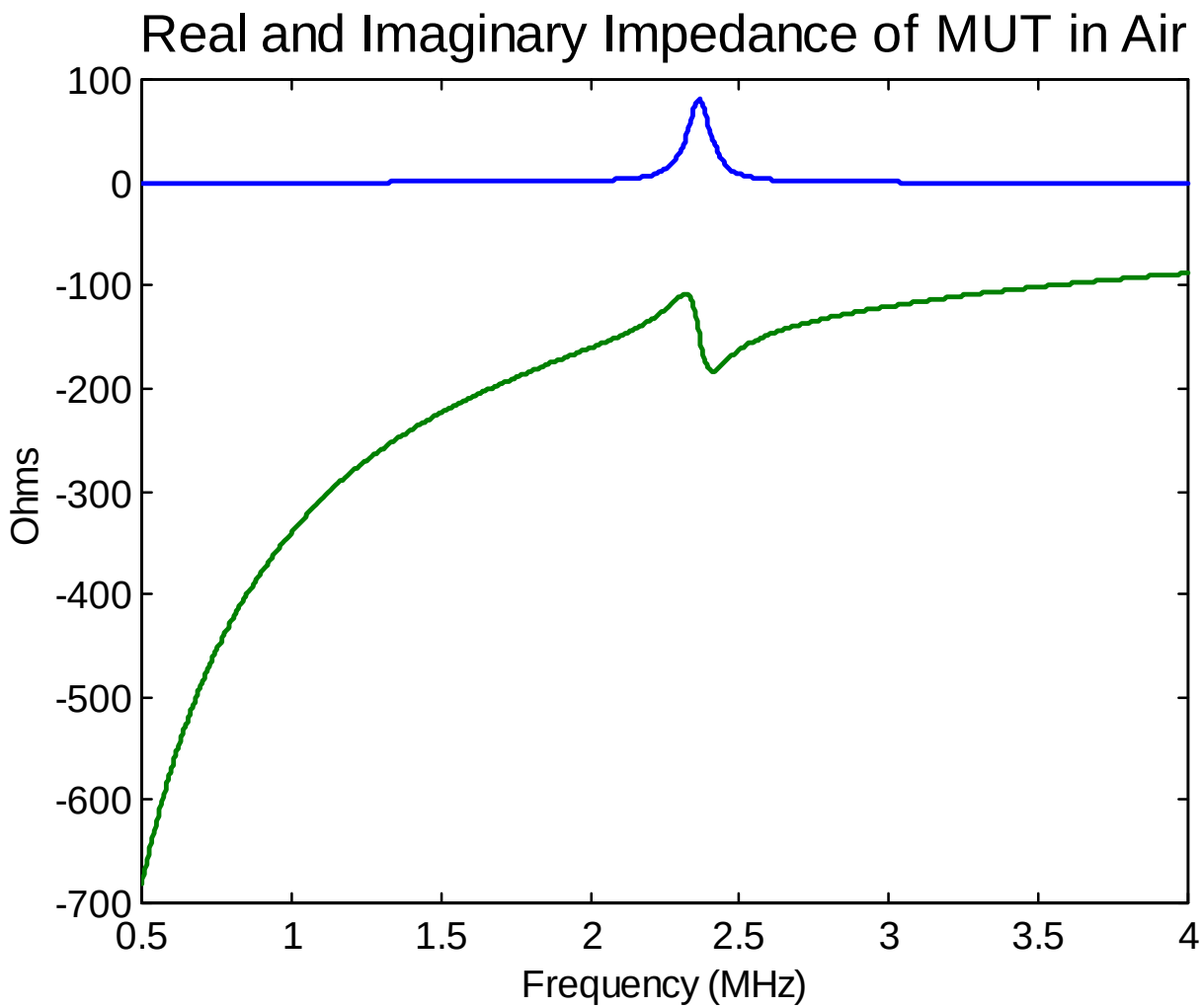


Fabrication Process

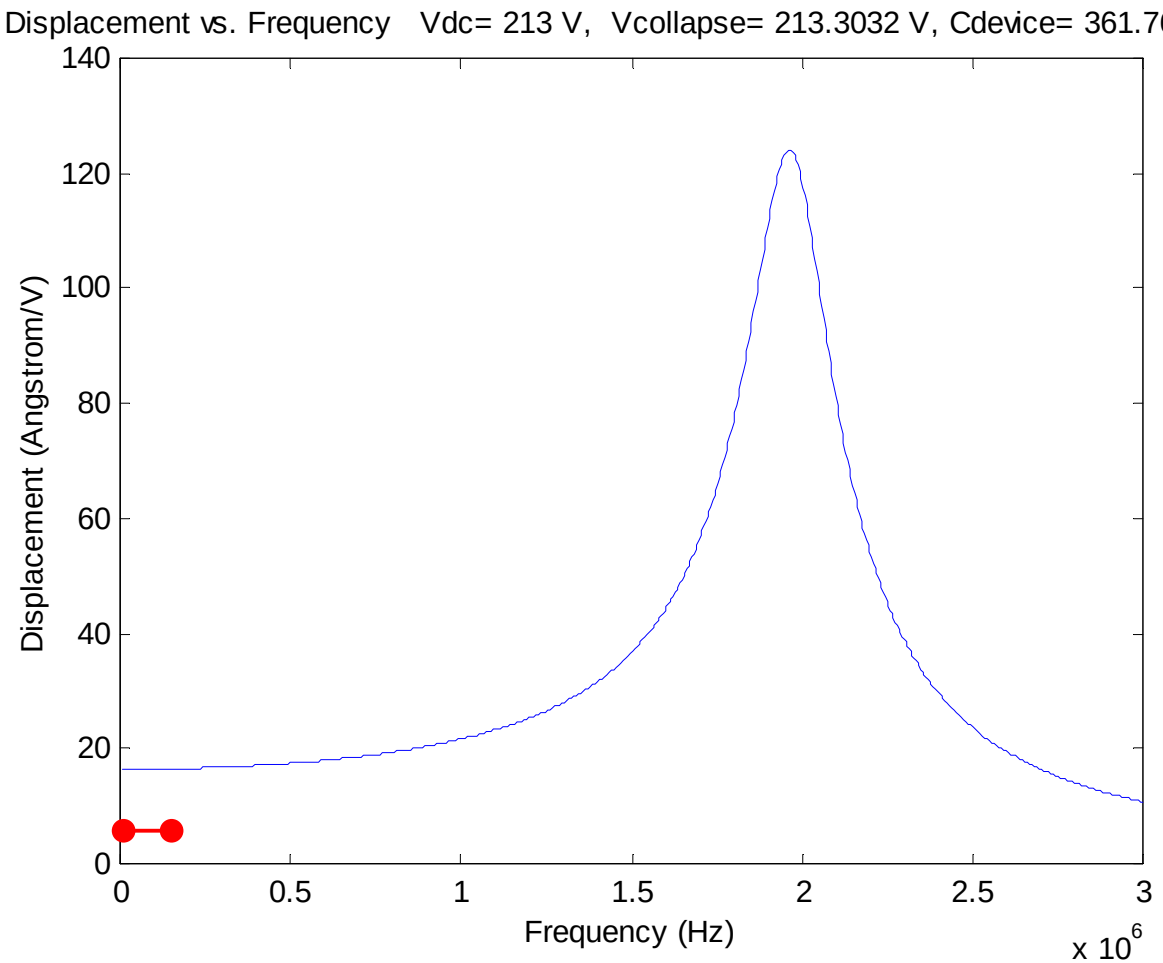


- High density doping
- LPCVD nitride deposition
- Amorphous silicon deposition
- Lithography and etch
- LPCVD nitride deposition
- Via and sacrificial etch
- Vacuum sealing
- Metal deposition and patterning

Input Impedance of cMUT in Air

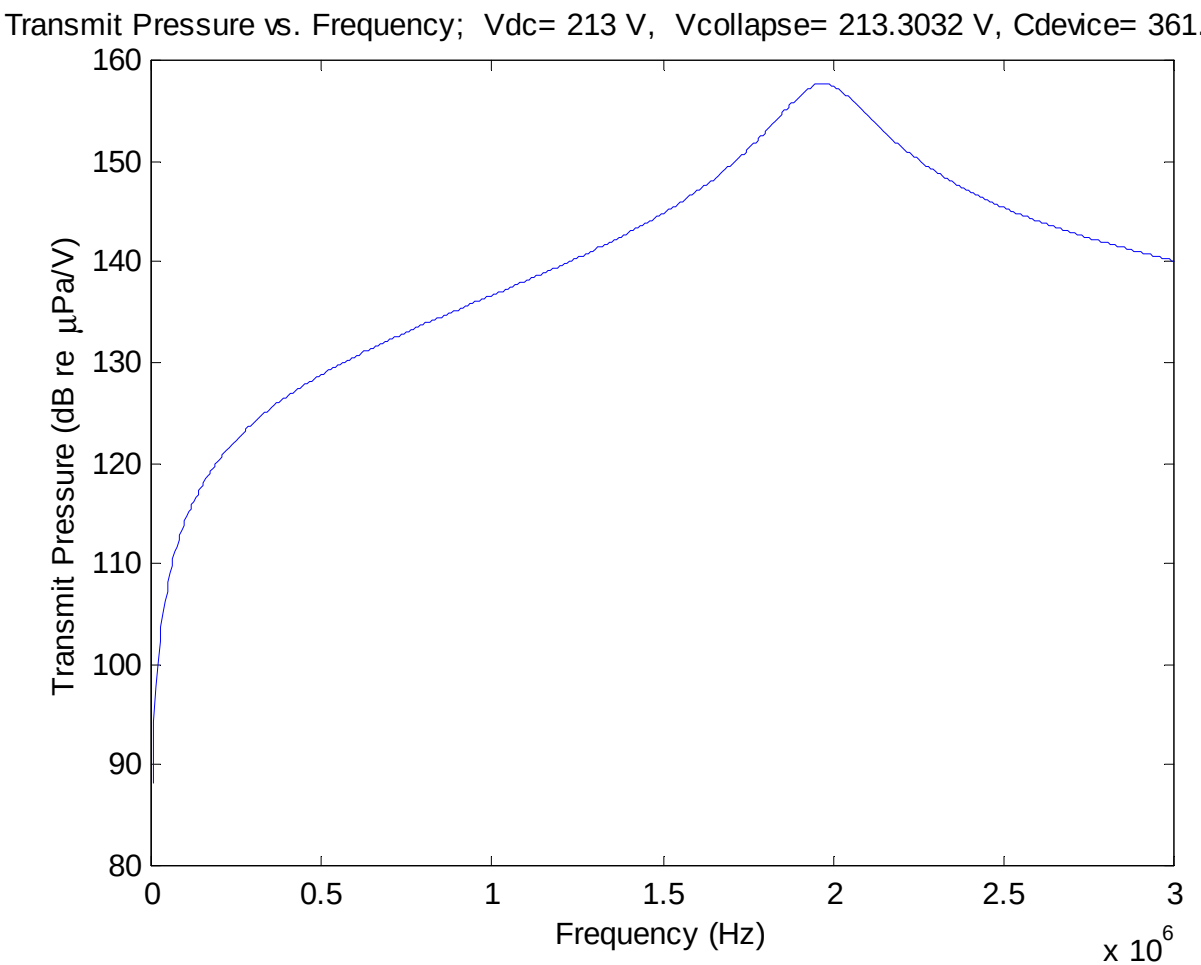


Average Displacement of a Membrane

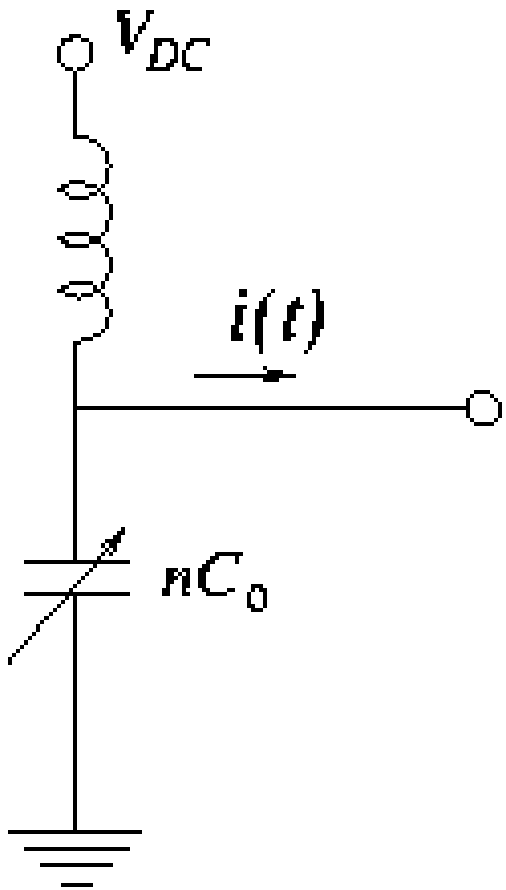


Broad band operation below resonance

Transmit Pressure of cMUT



Conventional Detection



$$I_{out} = V_{DC} 2\pi f_1 n C_0 \frac{\Delta x}{x_0}$$

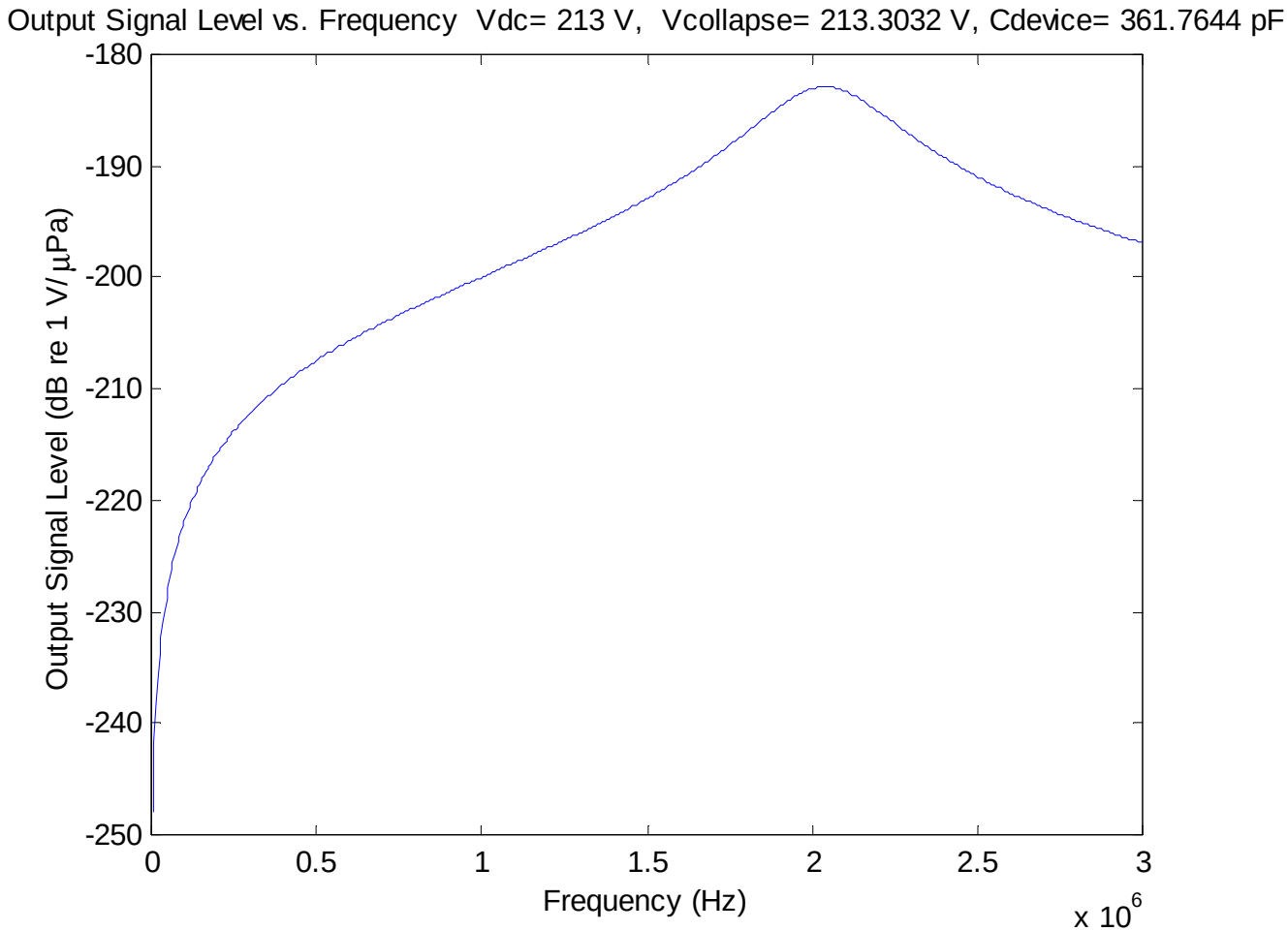
Receive Output of Conventional Detection Method

1cm x 1cm X-ducer

Membrane:

- 50 ìm diameter
- 1 ìm gap
- 1 ìm thickness
- Silicon Nitride

20% Parasitic C



Signal to Noise Ratio of Receiver

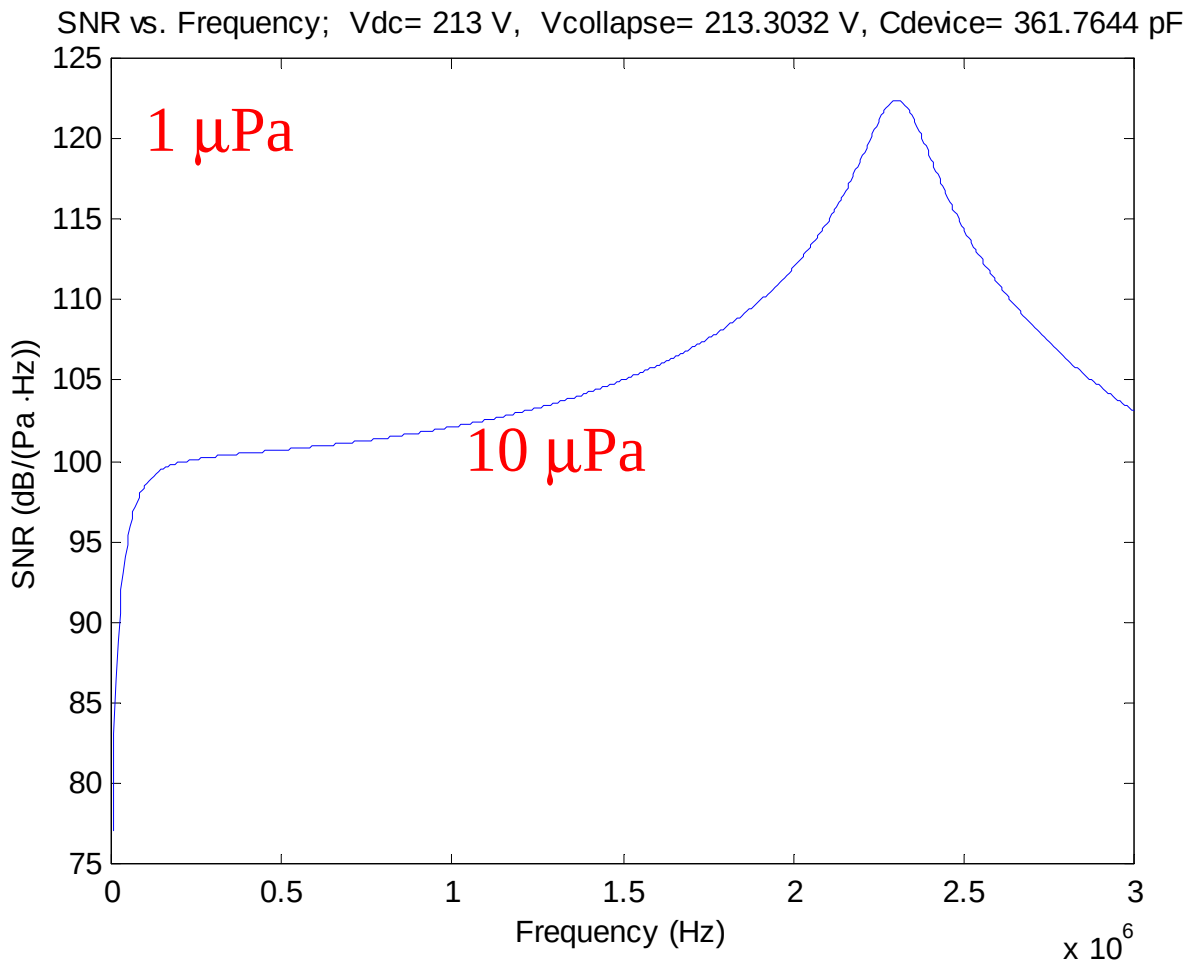
Amplifier:

Rin = 100 Ù

Cin = 1 pF

Vna = 1.4 nV/√Hz

Ina = .01 pA /√Hz



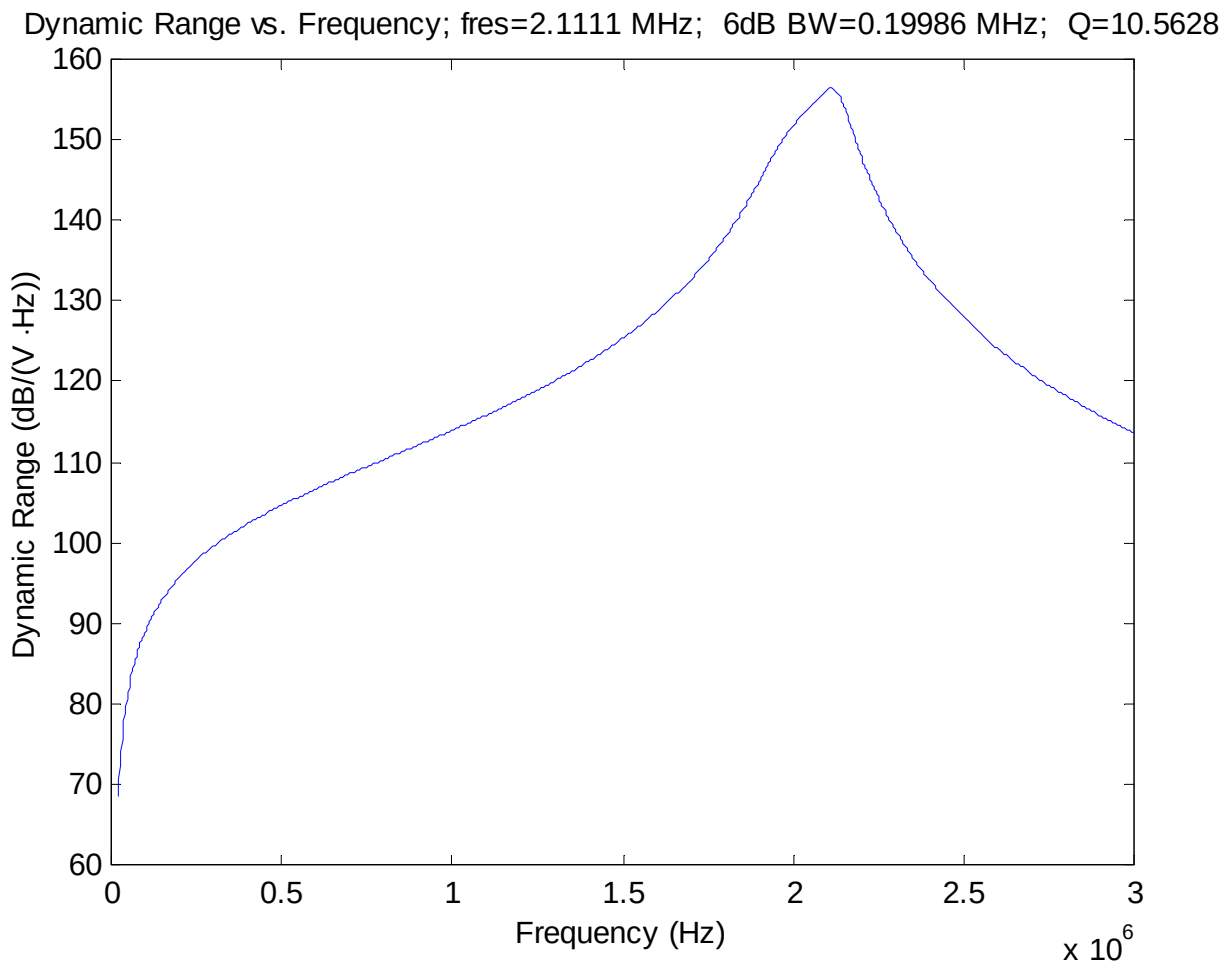
Dynamic Range of cMUT Air Transducer System

Transmitter:

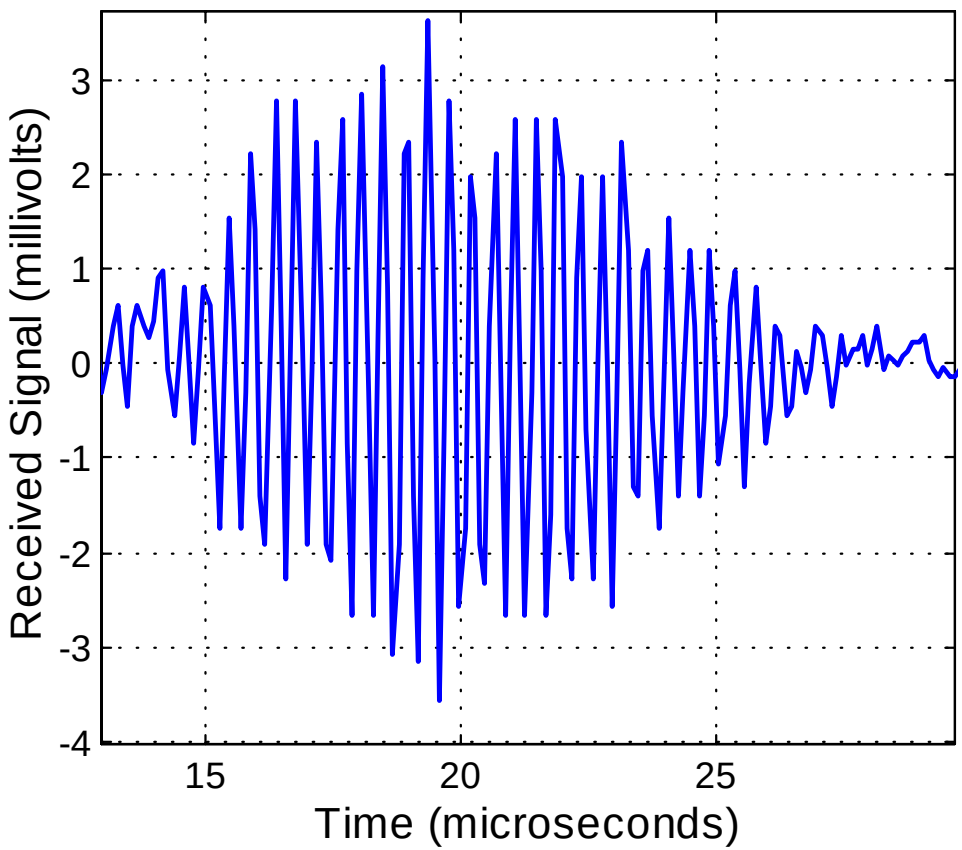
Source R = 50 Ω

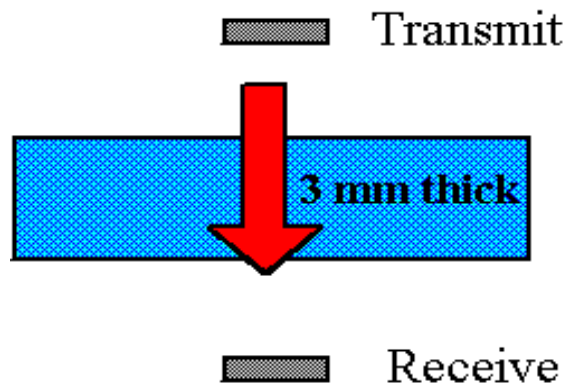
Receiver:

Previous slide



Transmission Through Aluminum at 2.3 MHz





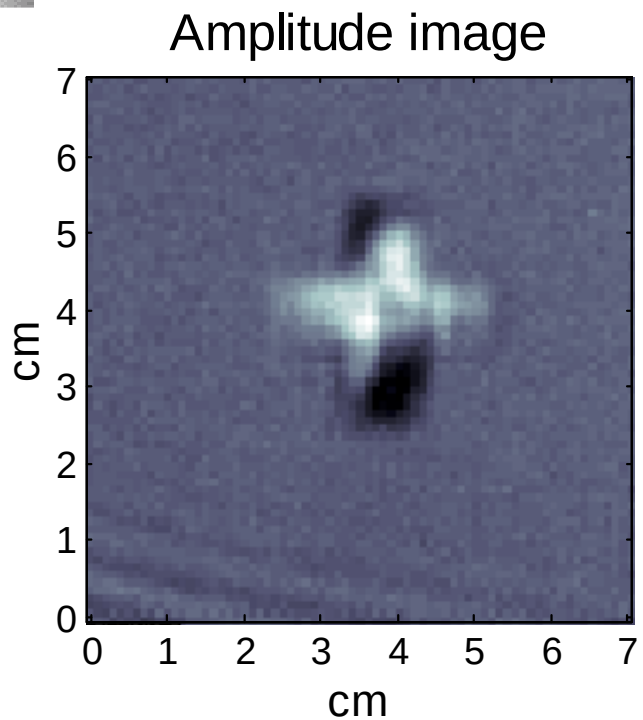
82 dB loss in 3 mm Al

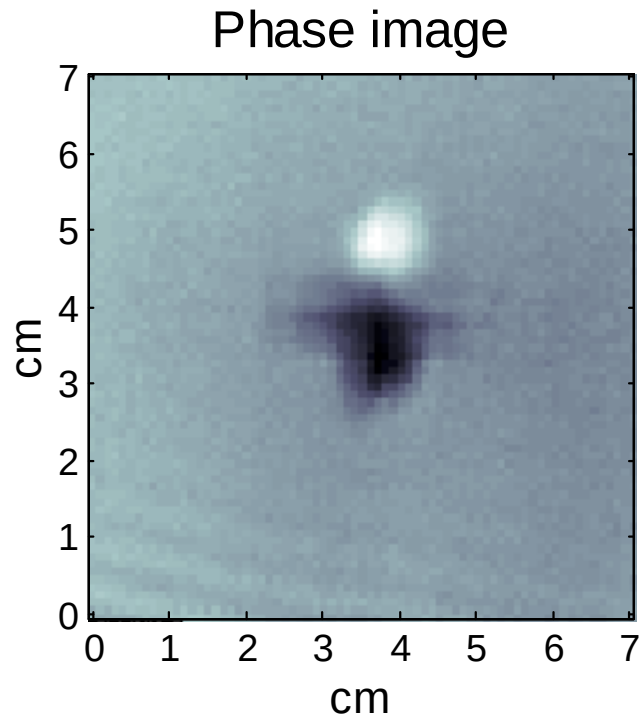
16 dB SNR

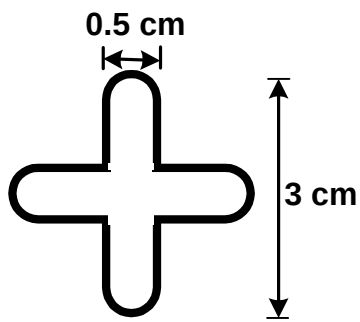
+ 5 dB loss in 0.6 cm air

103 dB System Dynamic Range

Transmission Image of Aluminum



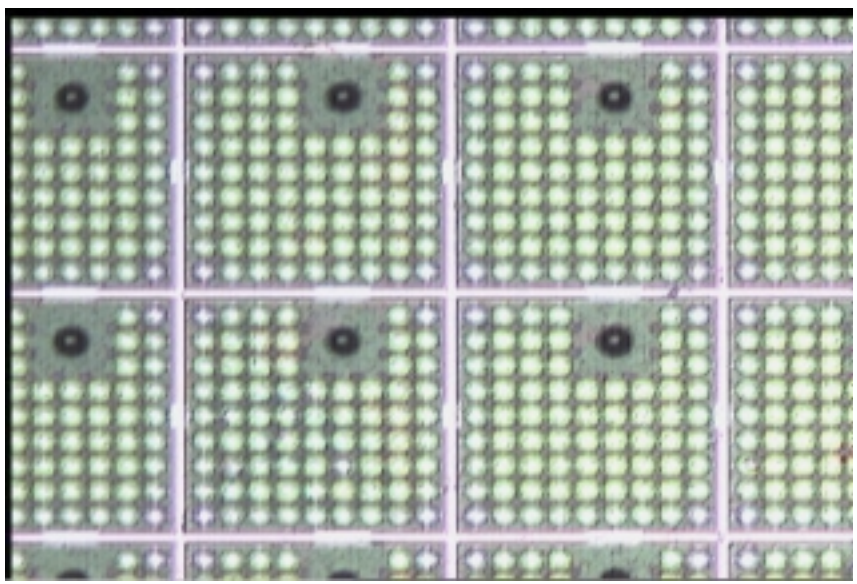


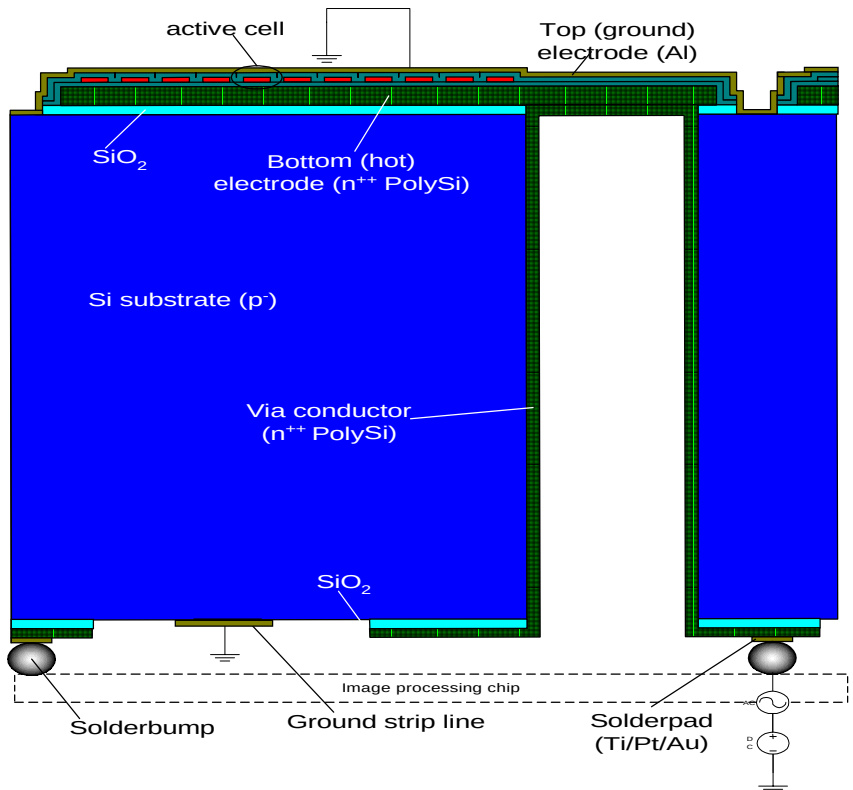


0.5 mm deep milled pattern on underside of 3 mm thick aluminum

Accomplishments of Present Technology

- Large dynamic range systems from 800 kHz - 11 MHz
- Single element, 1-D and 2-D arrays
- Through wafer contact vias
- Flip-chip bonding to integrate ultrasonics and electronics

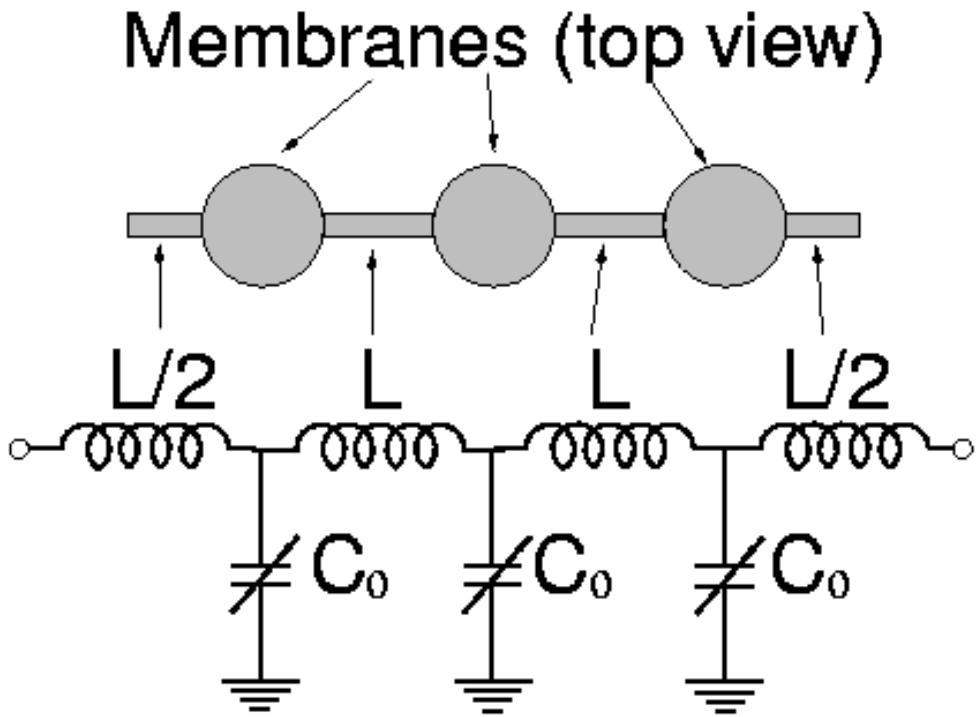




Broadband Detection: cMUTs as Elements of a Transmission Line

$$Z_a = \sqrt{\frac{L}{C_0}}$$

$$\beta = 2\pi f_0 \sqrt{LC_0}$$



Incident sound wave modulates the phase of an HF signal applied to the transmission line.

Courtesy of Ergun and Atlalar (Bilkent University)

Comparison of Conventional and Broadband Detection Schemes

$$I_{out} = V_{DC}\, 2\pi f_1 n C_0 \frac{\Delta x}{x_0}$$

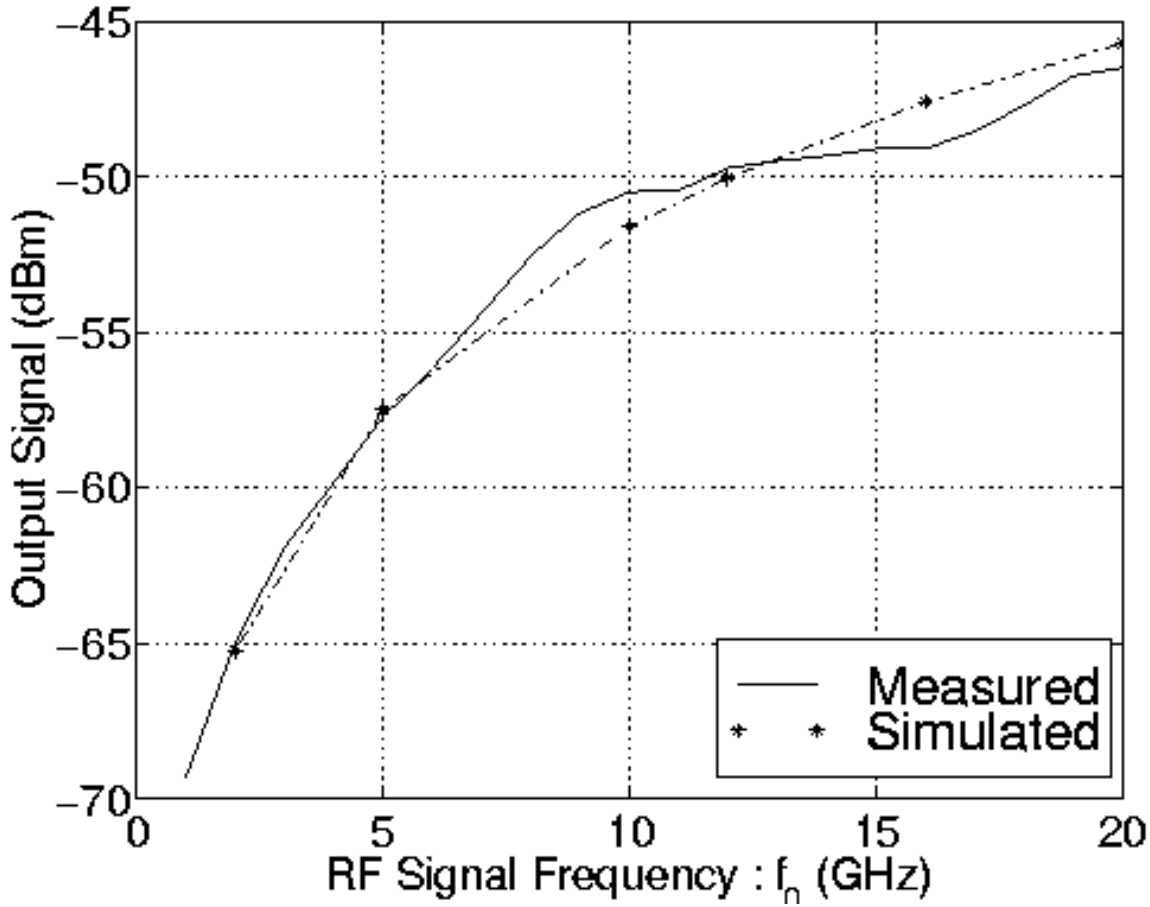
$$I_{out} = \frac{V_{RF}}{4}\, 2\pi f_0 n C_0 \frac{\Delta x}{x_0}$$

- Higher Sensitivity
- Broadband
- No dc necessary
- The lower the frequency, the better the sensitivity

Variable	Typical
V_{RF}	2 V
V_{DC}	100 V
f_0	10 GHz
f_1	0.1 MHz
Ratio	500

Courtesy of Ergun and Atlalar (Bilkent University)

Broadband Detection: Experimental Results



Courtesy of Ergun and Atlalar (Bilkent University)

Conclusions



- Surface micromachining can achieve low frequency (20-200 kHz) receivers.
- A broadband detection scheme allows operation over dc-GHz range.
- 1-D and 2-D arrays enable direction sensing.
- Through wafer vias enable integration to electronics via flip-chip bonding.